TD-04-042
09/04

Calculation of the Effect of Coil Rotation on the Fringe Fields of Tevatron Dipole Magnets

P. Bauer[1]

Fermilab, Technical Division

1) INTRODUCTION

The question was recently posed if possible rotations of the coils with regard to the yoke in Tevatron dipoles could be detected through fringe field measurements from the outside of the magnet as they are installed in the tunnel. The calculations presented in the following intend to answer this question with results from finite element simulations of the fringe fields of a simplified model of the Tevatron dipole magnet.

2) FE-MODEL

An OPERA2D[2] finite-element model of the Tevatron dipole magnet was used in the fringe field calculation. The finite element model, shown in Figure 1, represents a complete coil cross-section that includes all four quadrants of the coils and yoke as well as a vast air region to implement the surroundings and emulate infinity. The model also includes a (fine-meshed), 23 mm wide strip around the magnet yoke. The fringe field data were extracted from the field profiles in this region.

The particular model developed here uses a simplified, rectangular representation of the Tevatron dipole yoke geometry. Neither does it include the thick, welded plates, which bend around the corners, nor the key-groves or other fine details. Therefore the fringe fields obtained in the calculations here might only provide information about the order of magnitude but not the exact shape of the real fringe fields. This, however, should not matter given that the purpose of this calculation is to provide an order of magnitude estimate of the effect of coil role on the fringe-field of the Tevatron dipoles.

The coils in the model are simplified shell-types, with no distinction between the bus and regular turns. Therefore the multipole content as well as the transfer function calculated are only within several percent of those in the real magnet. Obviously the current simulated in the coils is that for collision conditions.

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[1] e-mail: pbauer@fnal.gov
[2] OPERA v.8.5, trademark of Vectorfields Limited

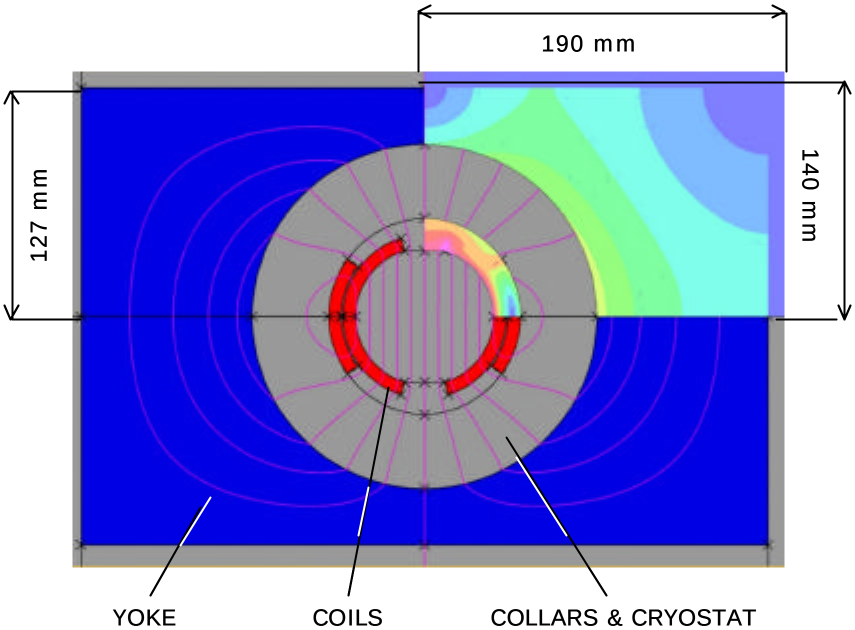


Figure 1: Example of OPERA2D model of Tevatron cross-section including yoke.

3) FRINGE FIELDS VS COIL ROTATION ANGLE

The example in Figure 2 shows the magnetic field strength in the yoke as well as in the 23 mm wide strip on top and bottom of the yoke at full current in the coils. These are the type of results that are being exploited in the subsequent plots. The discontinuity that can be seen in this figure at the edge of the yoke is related to the expected discontinuity of the horizontal (parallel to the yoke edge) component of the magnetic induction at the ferro-magnetic boundary.

The subsequent plots (Figure 3 to Figure 6) show the field profiles along a line at y=140 mm, between x=±150 mm, both measured from the center of the magnet. This line goes approximately through the middle of the “fringe-strip” mentioned above and shown in Figure 1. It is in fact located 13 mm above the yoke top surface such as to be accessible to measurement. The fields B_x, B_y and B are shown for several counter-clockwise rotation angles of the coils with respect to the yoke: 0, 0.2 (0.0115), 2 (0.115) and 17 (0.974) mrad (deg).

Figure 7 Figure 8 show the effect of the roll angle on the horizontal and vertical field components separately.

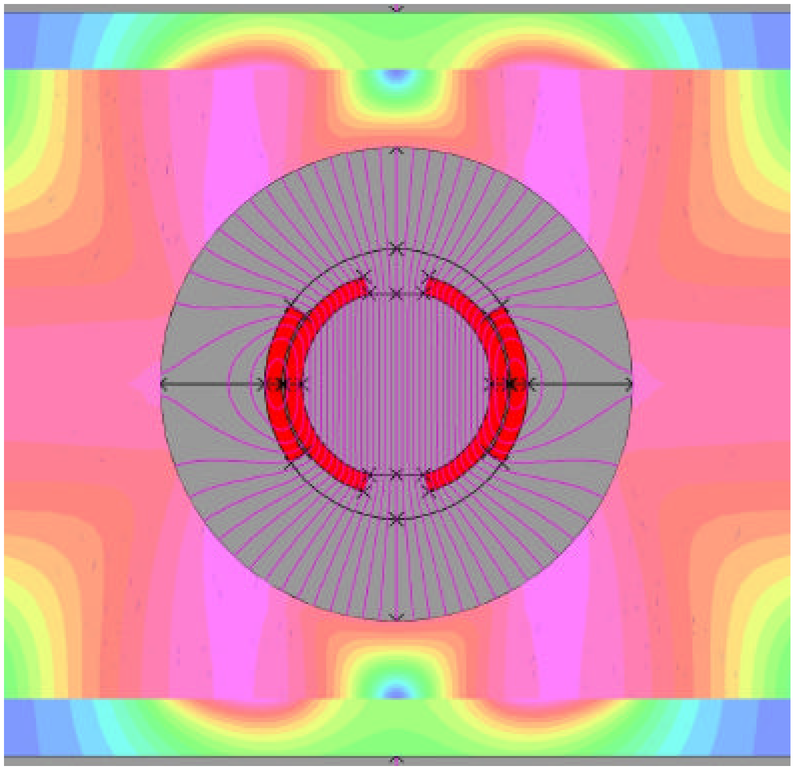


Figure 2: Magnetic field in yoke and above the yoke in Tevatron dipole magnet at collision.

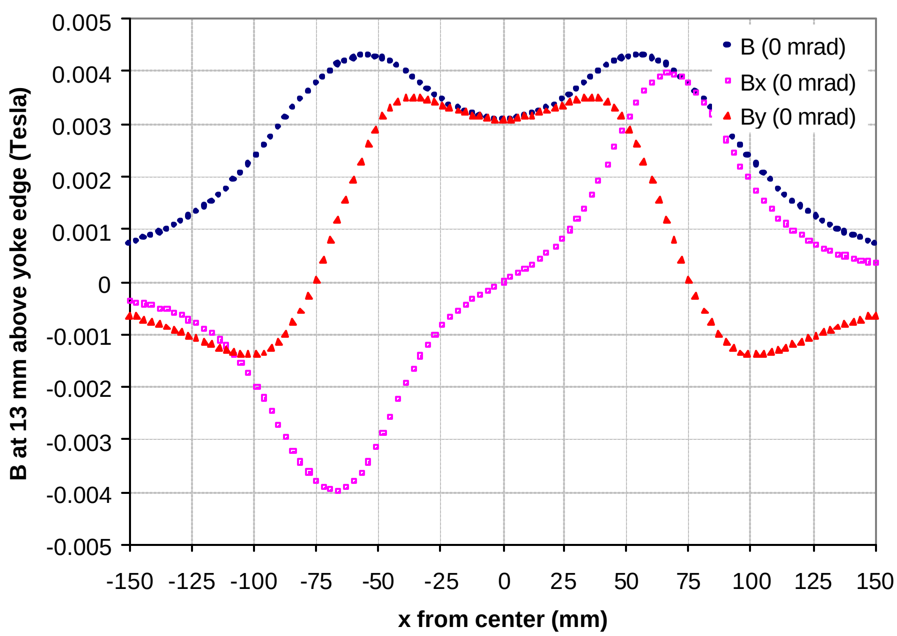


Figure 3: Fringe field in Tevatron dipole magnet along horizontal line parallel to the top edge of the iron yoke (13 mm above the top edge of the yoke) for the case of no rotation of the coils within the yoke.

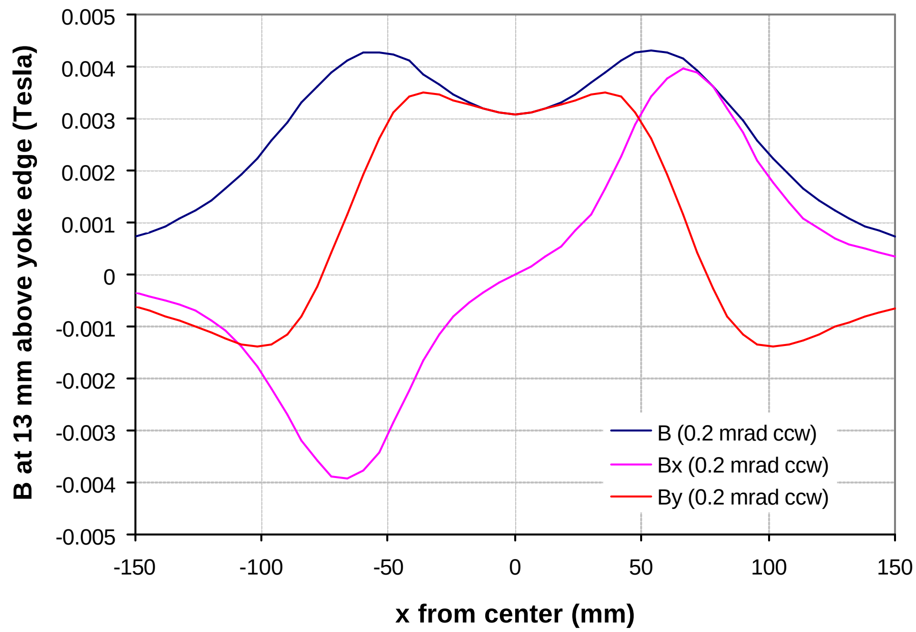


Figure 4: Fringe field in Tevatron dipole magnet along horizontal line parallel to the top edge of the iron yoke (13 mm above the top edge of the yoke) for a 0.2 mrad (counter-clockwise) rotation of the coils within the yoke.

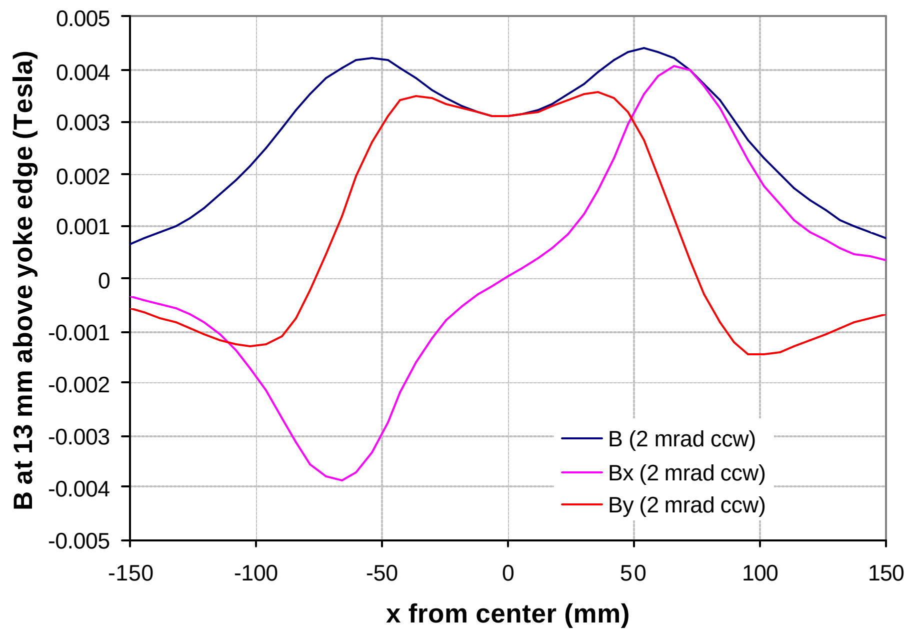
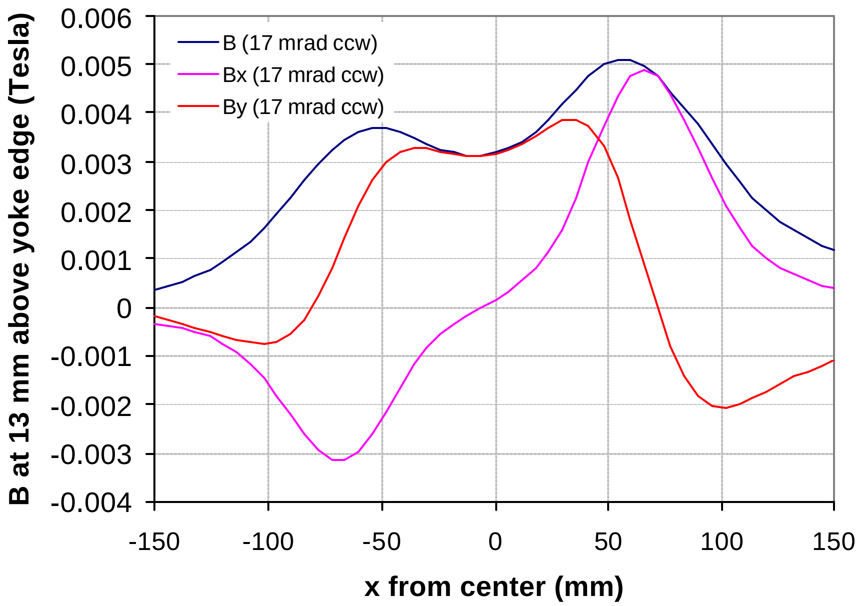


Figure 5: Fringe field in Tevatron dipole magnet along horizontal line parallel to the top edge of the iron yoke (13 mm above the top edge of the yoke) for a 2 mrad (counter-clockwise) rotation of the coils within the yoke.



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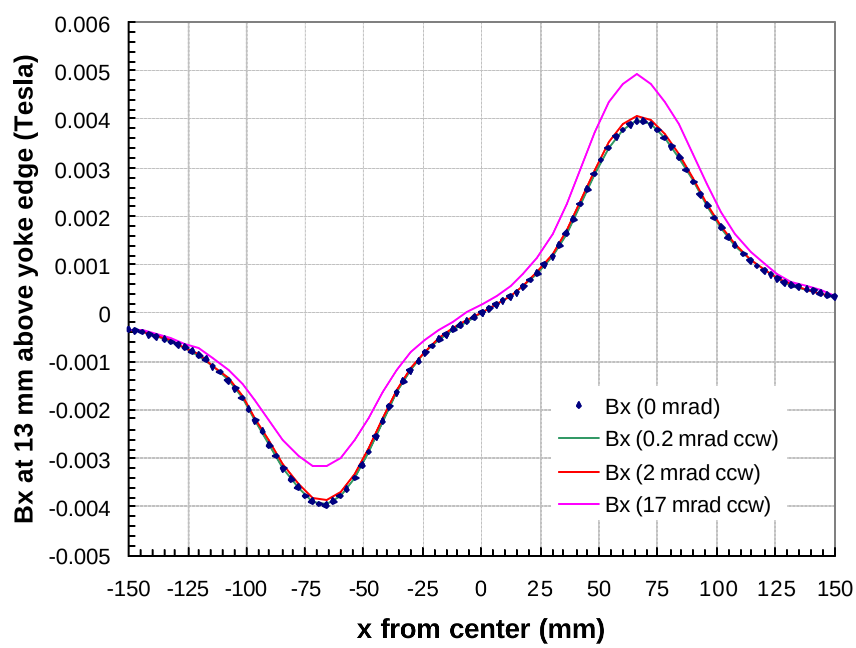
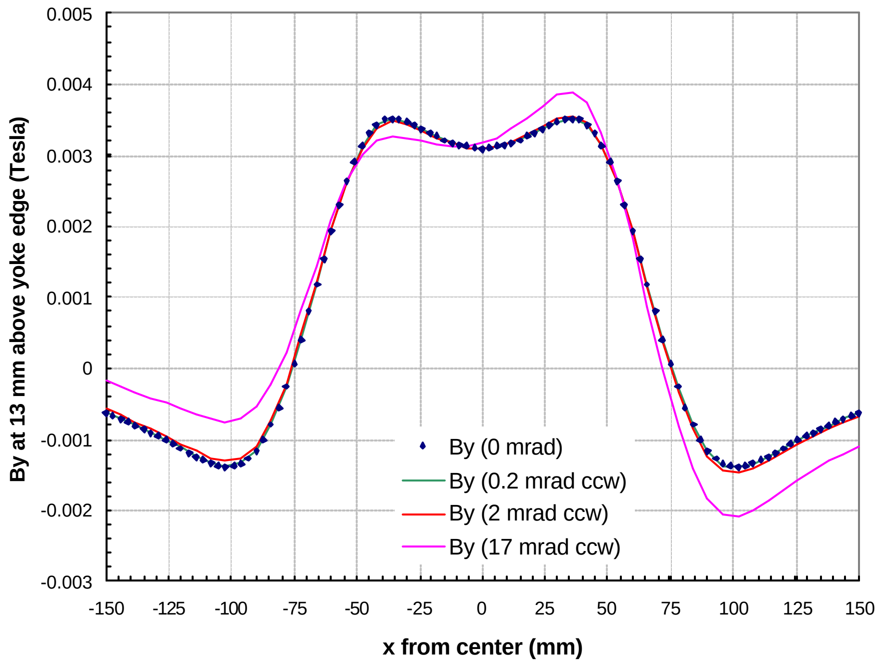


Figure 7: Bx along y=140 mm line for different (counter-clockwise) rotation angles of the coils within the yoke.



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4) SUMMARY

The simulations presented above were conducted to understand if the rotational angle of the coil with respect to the yoke can be inferred from fringe field measurements. Figure 9 shows the change in the B_x component (on the left half of the yoke) versus coil rotational angle. The plot indicates a more or less linear behavior with ~0.5 mT per 10 mrad, which is very small. The change of B_y with rotational coil angle is similar in magnitude.

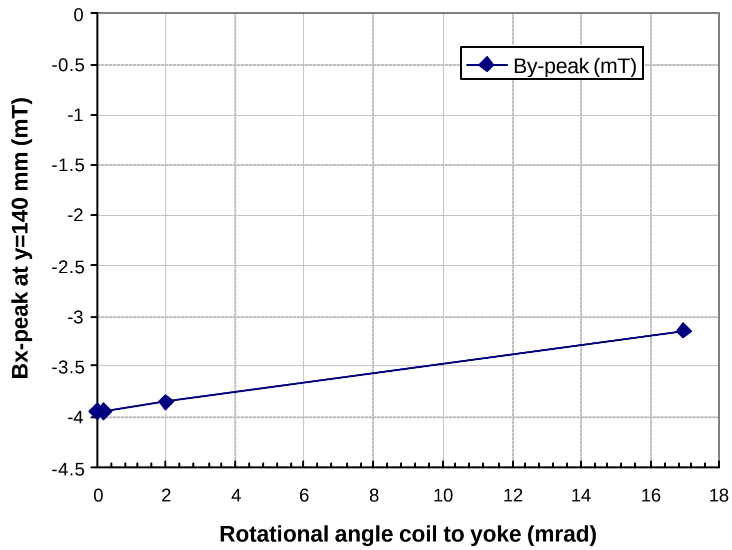

Figure 9: Change of Bx peak in mT versus rotational angle between coil and yoke. The peak was determined at the side of the yoke toward which the coil rotates (here it is the left side for a counter clock-wise rotation of the coil).

Conclusions and Recommendations:

Given an earth field intensity of ~0.2 mT it appears feasible to detect make a successful fringe field measurement. The coil fringe field should stand out from the background. It appears difficult, however, to quantify the rotational angle with this method. In particular the difference between a 0.2 mrad and a 2 mrad rotation requires a resolution of less than 0.1 mT, which is beyond the typical measurement accuracy of, say a Hall-probe system given the expected background and "rough" operating conditions in the tunnel.

Another problem, which also needs to be taken into account, is that the rotational angle of the coil with respect to the coil is expected to vary long the length of the magnet, such that a fringe-field profile in one location along the magnet length might not deliver the information needed for a correction of the coil roll. Furthermore, such a measurement requires a scan across x, which is a time consuming measurement.
Last but not least one should also not forget that the calculations presented here have been obtained with a simplified model of the iron yoke of the Tevatron magnet. The real Tevatron dipole yoke also includes thick welded plates around the corners (with air gaps underneath), which can considerably distort the fringe field patterns and complicate the measurement even further by making the signal even smaller.

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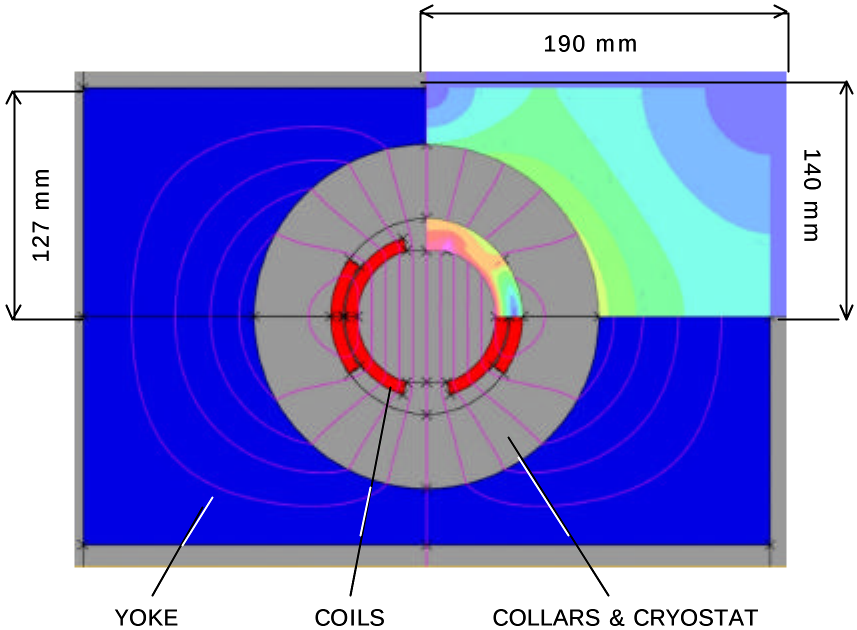

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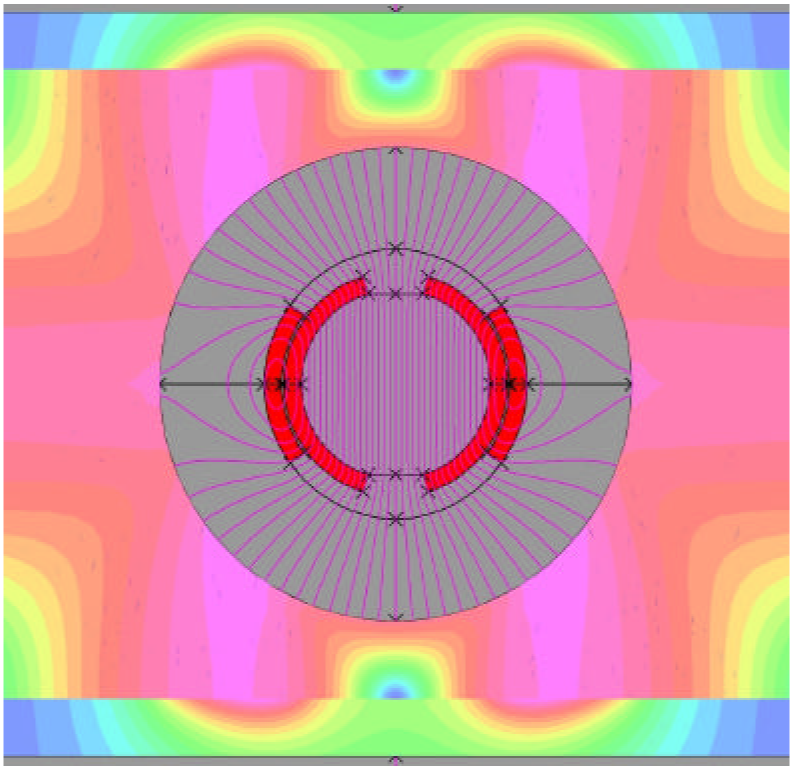

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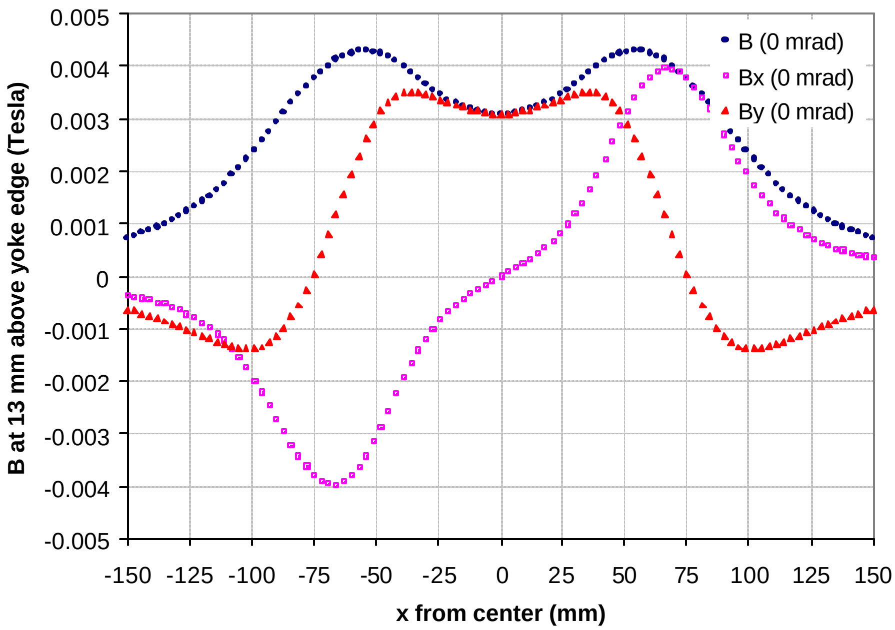

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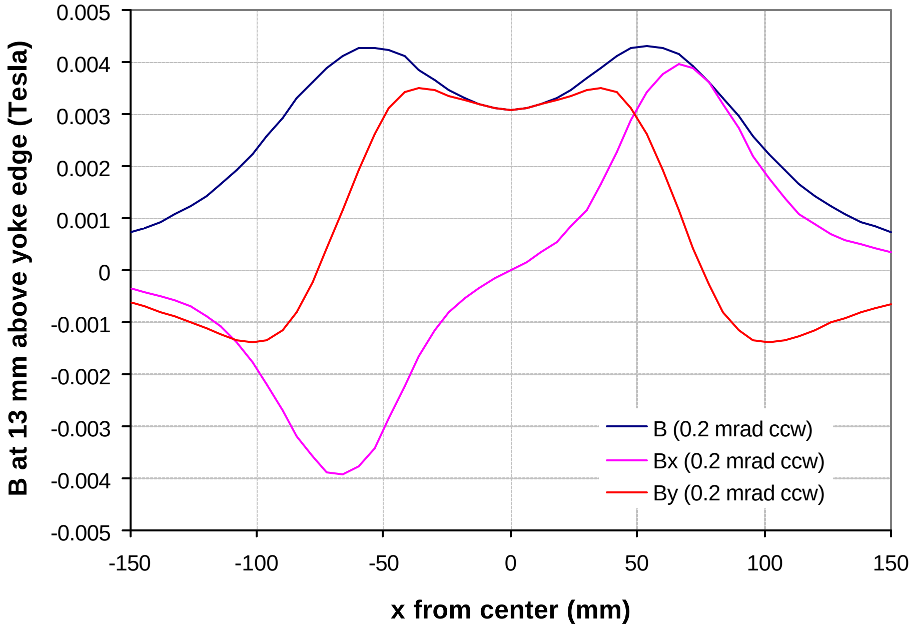

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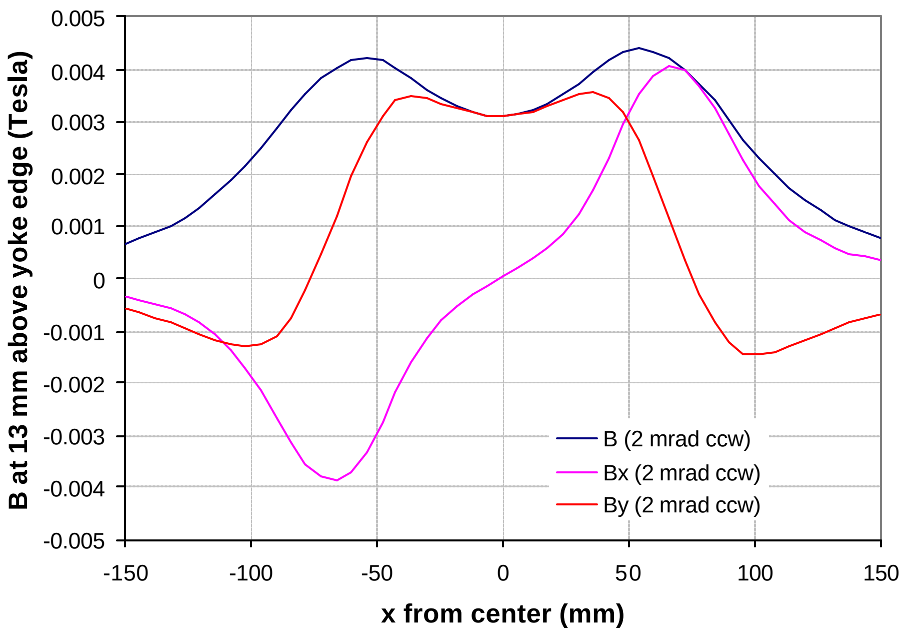

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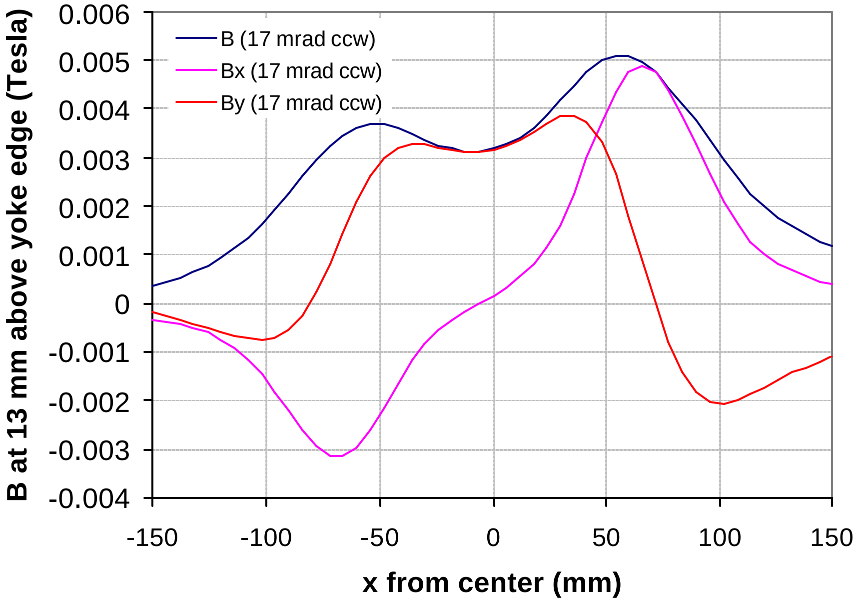

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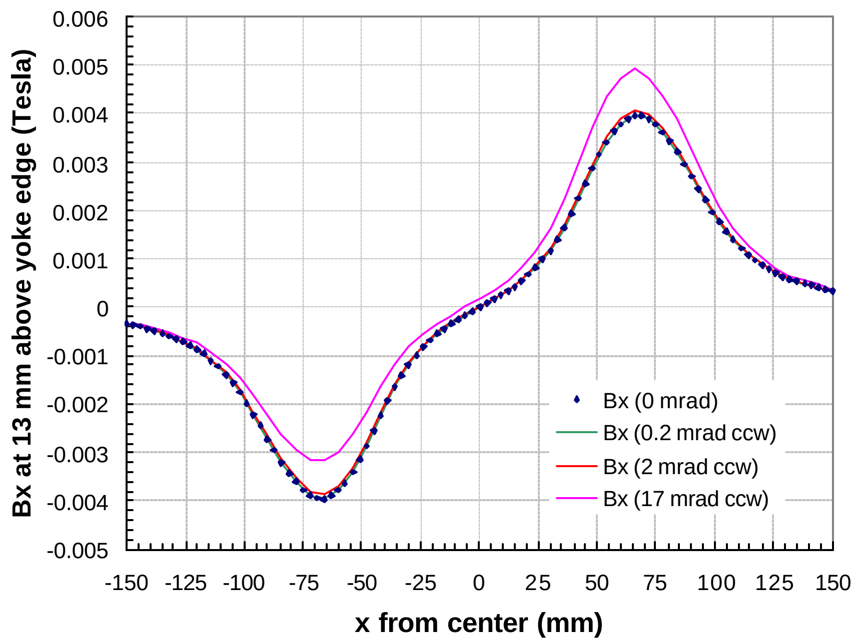

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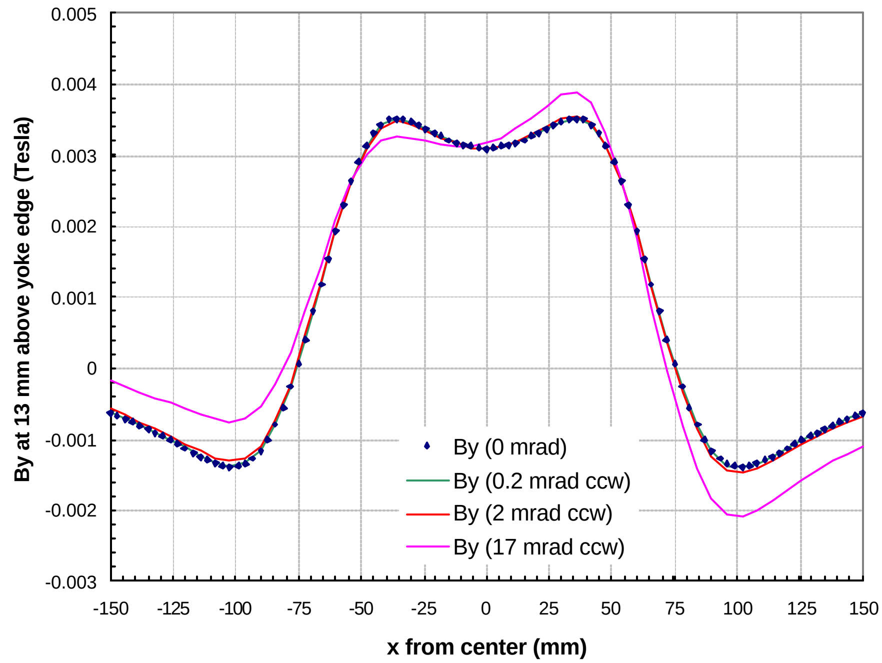

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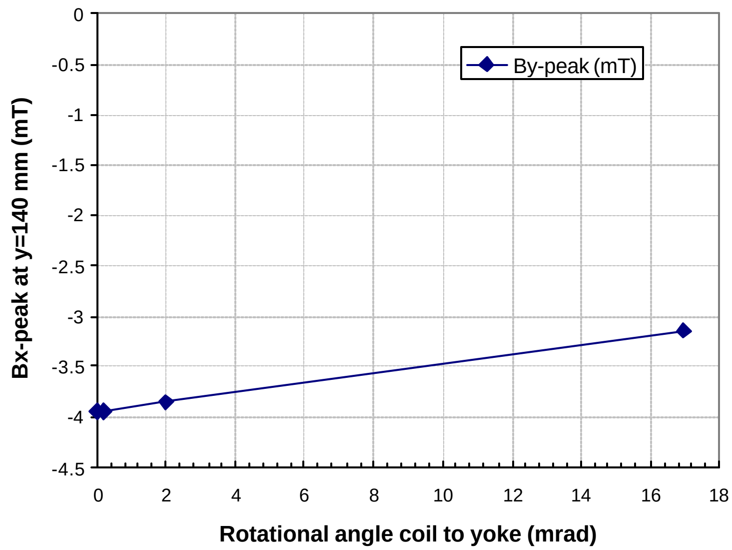

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